(12) UK Patent Application (19) GB (11) 2 149 226 A

(43) Application published 5 Jun 1985

(21) Application No 8421692

(22) Date of filing 28 Aug 1984

(30) Priority data
(31) 3331940 (32) 5 Sep 1983 (33) DE

(51) INT CL[4]
H02K 29/06

(52) Domestic classification
H2A TV

(56) Documents cited
GB 1588671 GB 1563229

(58) Field of search
H2A

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(54) Collectorless D.C. motor

(57) Three-phase collectorless D.C. motor with a permanent-magnet rotor magnet arrangement (11) having at least two pole pairs (12,13) and a star-connected three-conductor stator winding, the winding's conductors (22,23,24) being arranged non-overlapping in slots of a slotted stator (15), with their currents being controlled via at least three semiconductor elements (26,27,28) by at least three magnetic-field-sensitive position sensors (30,31,32), the latter in turn being controlled by the rotor magnet arrangement. The position sensors are distributed along the stator's circumferential direction in such a manner relative to the stator winding's conductors that, in each instance, that one position sensor which effects the commutation of the winding's conductors is provided in the region of the stator in which a current-carrying coil is present neither before nor after the commutation operation.

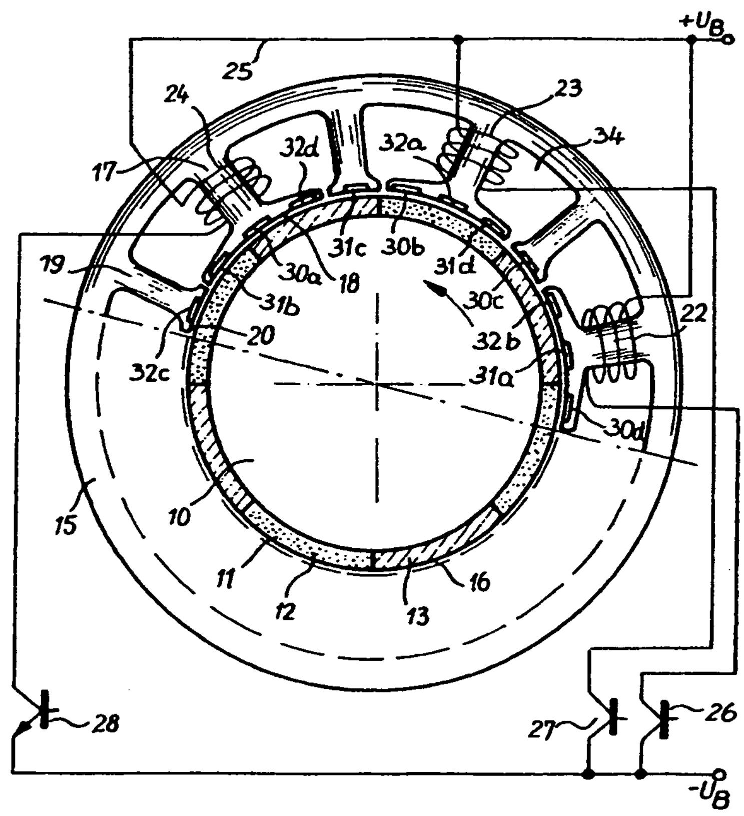

Fig. 1

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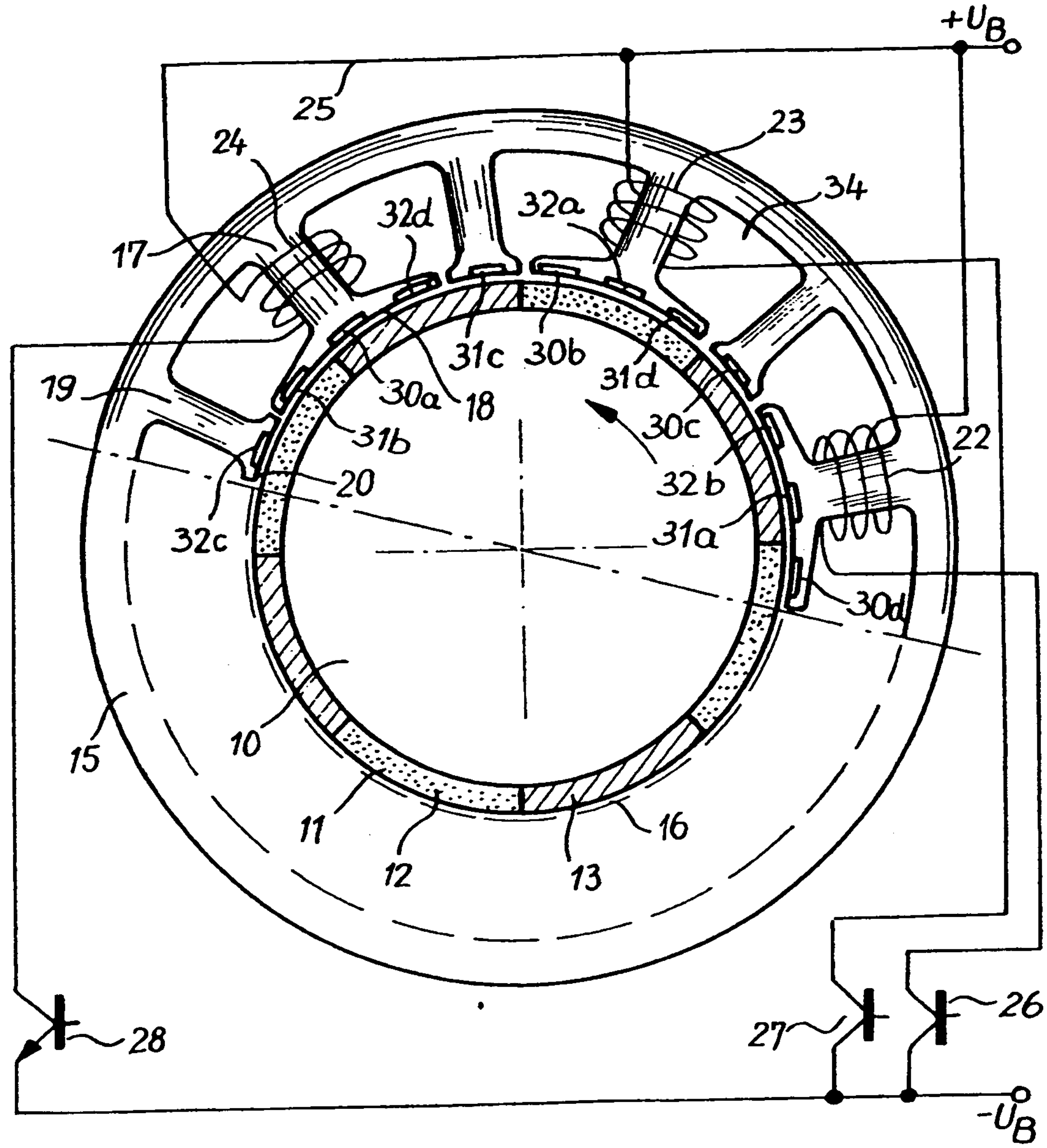
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Fig. 1

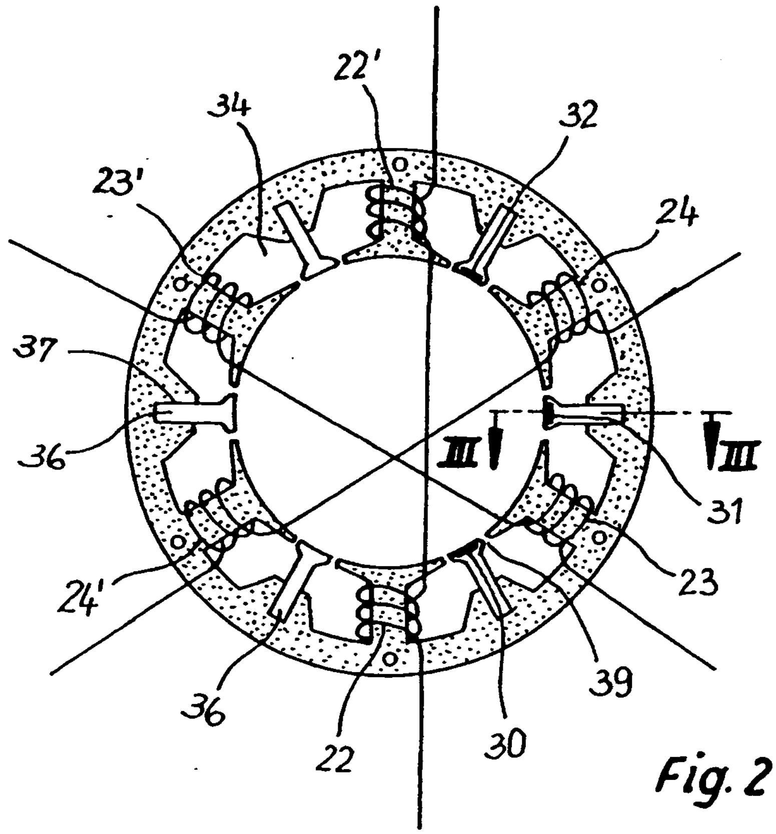

Fig. 2

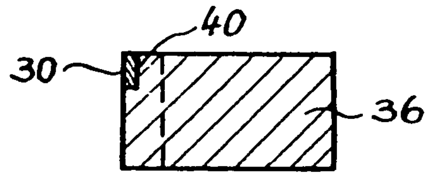

Fig. 3

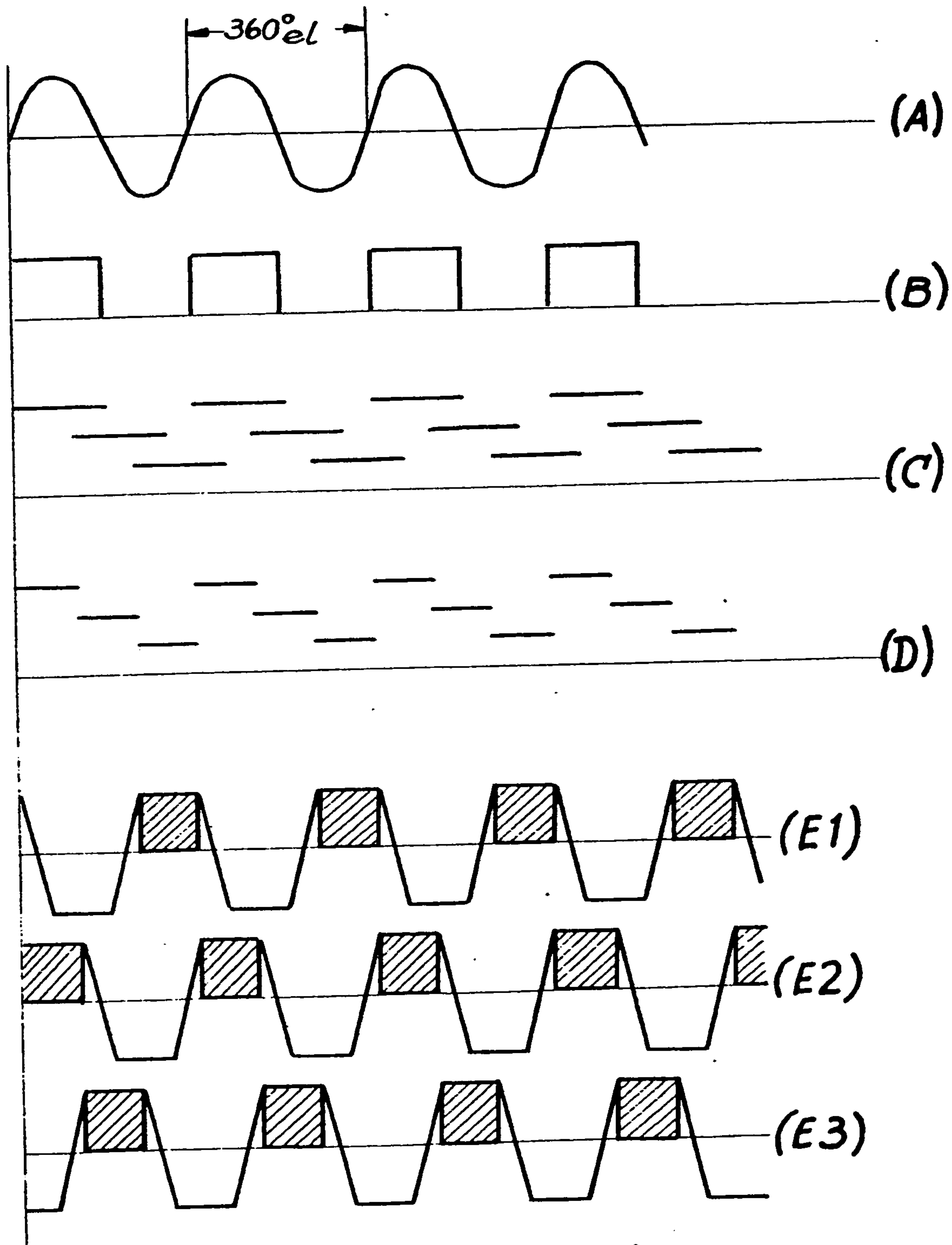

Fig. 4

SPECIFICATION

Collectorless D.C. Motor

The invention concerns a three-phase collectorless D.C. motor with a permanent-magnet rotor magnet arrangement having at least two pole pairs and a star-connected, three-conductor stator winding, the winding's conductors being arranged non-overlapping in slots of a slotted stator, with their currents being controlled via at least three semiconductor elements by at least three magnetic-field-sensitive position sensors, the latter in turn being controlled by the rotor magnet arrangement.

With motors controlled in this manner, especially in the case of higher powers, there arises the problem of the field from the stator windings influencing the magnetic-field-sensitive position sensors. As a result of such influencing, the commutation time points are in undesirable fashion shifted from the predetermined optimal position, and the more so the higher the winding's current.

Therefore an object of the invention is to so design a D.C. motor of the stated type as to substantially prevent a shifting of the commutation time points under the influence of the currents flowing in the stator winding.

According to the inventin this object is achieved in surprisingly simple manner, in that the position sensors are distributed along the stator's circumferential direction in such a manner relative to the stator winding's conductors that, in each instance, that one position sensor which effects the commutation of the winding's current from one to another of the winding's conductors is provided in the region of the stator in which a current-carrying coil is present neither before nor after the commutation operation.

With the motor according to the invention the magnetic-field-sensitive position sensors remain uninfluenced by the stator winding's field during the commutation. Even in the case of higher winding currents there does not occur an undesired displacement of the commutation time points.

In accordance with a further feature of the invention the number of stator poles stands in the ratio 3:4 to the number of rotor poles, each of the stator poles having a breadth of substantially 180°-el. As a result a chording is avoided. A particularly high efficiency is achieved. The torque developed by the motor is substantially constant.

It has proved especially advantageous to locate the position sensors substantially midway, considered in the circumferential direction, between those neighboring coils as between which the commutation of the winding's current occurs under the influence of the respective position sensor.

According to a further embodiment the position sensors can also be located substantially on the radial symmetry axis of the stator pole which is carrying that one of the coils not involved in the commutation operation triggered by the particular position sensor.

The motor can be designed as a three-pulse motor or else as a six-pulse motor, in the latter case it having preferably at least four magnetic pole pairs.

Preferably, at the air gap, the space remaining in the circumferential direction between each two neighboring, preferably 180°-el.-wide stator poles is substantially filled up by an unwound auxiliary stator pole. In an effective manner the auxiliary stator poles avoid a magnetic jolt, because an approximately uniform induced voltage is obtained over a relatively large angle, which means a uniform torque at constant current. Without such auxiliary poles between 180°-el.-wide stator poles, in the case of a ratio of stator poles to rotor poles of 3:4 the stator poles would be, functionally, wider than 180°-el. because a great part of the rotor's magnetic field, appearing in the pole gaps, would be attracted to the stator poles. There would set in in undesired manner a chording action.

In the case of the motors set forth above—but also in general in the case of collectorless D.C. motors with a permanent-magnet rotor magnet arrangement and a slotted stator carrying a stator winding wound without overlap, the stator having a succession of integrally interconnected poles, e.g. stamped out in conventional manner from Dynamo sheet metal—it is desired that, on the one hand, the slot openings be kept small but, on the other hand, that there be assured windability suitable for fabrication needs. In accordance with the invention this problem is solved in that there is inserted between the poles a succession of auxiliary poles which as separate parts can be connected to the stator afterwards. During the winding procedure the auxiliary poles are left off. As a result the winding can be installed in the stator slots unproblematically. The auxiliary poles are installed only when the stator windings have been formed. These later installable auxiliary poles can advantageously form the aforesaid unwound auxiliary poles.

In accordance with a further feature of the invention the auxiliary poles are insertable into recesses of the stator winding's core. Whereas the latter advantageously involves, in conventional manner, a stack of sheet metal, each auxiliary pole is preferably formed as a one-piece pole body. In particular the auxiliary poles can be formed from solid material or as sintered bodies. Because the auxiliary poles, in correspondence to their relatively short circumferential extent, accept only a relatively small magnetic flux, eddy-current losses, in particular, remain low even in the case of solid auxiliary poles. Manufacture from sintered iron has the advantage that by means of

powder-metallurgy techniques very exact shapes can be manufacturered without there being a need to thereafter do further material-removing machining work. Furthermore, for electro-technical applications there are commercially available also suitable siliconized iron types, such as e.g. from the Vakuum schmelze Company under the trade name "Trafoperm".

The auxiliary poles can be advantageously be provided with recesses suited for accomodating the position sensors; the latter can involve, in particular, Hall generators, Hall-IC's or similar magnetic sensors. In the case that sintering techniques are used such recesses can be formed in particularly simple manner.

The invention is explained in greater detail below with respect to preferred embodiments. In the accompanying drawings there is shown:

Figure 1 schematically, a sectional view of a D.C. motor according to the invention,

Figure 2 a view similar to Fig. 1 for a modified embodiment of the invention and,

Figure 3 a sectional view through an auxiliary pole corresponding to the line III–III of Fig. 2.

Figure 4 depicts a set of waveforms referred to in describing the preferred mode of operation of the motor.

The three-phase collectorless D.C. motor of Fig. 1 has a rotor 10, rotably mounted in a manner not illustrated in detail, with a permanent-magnet rotor magnet arrangement 11. The rotor magnet arrangement 11 is preferably formed from a rubber-magnet strip, i.e. a one-piece strip made of a mixture of hard ferrite, e.g., barium ferrite, and elastic material. The magnet strip is radially magnetized; its magnetization has the shape of a trapezoic, or approximately a trapezoid, extending over the pole pitch, with relatively small pole gaps. It forms in the illustrated embodiment four pole pairs which at their outer peripheral surfaces constitute, alternately, magnetic north poles 12 and magnetic south poles 13. It is to be understood that other magnetic materials can be used too, and that the rotor magnet arrangement can also be assembled from individual magnetic plates.

The rotor 10 is encircled by a stator 15, preferably in the form of a laminated stack of sheet metal, forming a cylindrical air gap 16. Only one half of the stator 15 is depicted; the other half is configured symmetrically in correspondence thereto. The stator 15 has six T-shaped main poles 17. The pole faces 18 of the main poles 16 face the air gap 16 and each extend for an angle of 180°-el., i.e., the width of each of the six main poles is, at the air gap 16, equal to the width of each of the eight rotor poles 12, 13. In this way, at the air gap 16, there result between the main poles 17 gaps which are each 60°-el.wide. These gaps are substantially filled up by auxiliary poles 19, i.e., the pole faces 20 of the auxiliary poles 19 extend for a breadth of almost 60°-el; they end at a small distance, in the circumferential direction, from the respective neighboring main-pole face 18. Each of the main poles 17 carries a stator coil, of which in Fig. 1 the three stator coils 22, 23, 24 are depicted. Corresponding stator coils—which can be connected in series with their respective diametrically opposite stator coils 22 or 23 or 24—are provided on the three non-illustrated main poles. The stator coils altogether form a star-connected, three-conductor stator winding whose constituent windings do not overlap one another. As a result there are obtained especially short winding heads, which is advantageous not only for spatial reasons but also leads to low winding resistance. In the arrangement of Fig. 1 the common or star junction of the stator winding is connected via a line 25 to the positive side $+U_B$ of a voltage source; the star junction is connected to a respective end of each of coils 22, 23, 24 whereas the other end of these coils is connected, via a respective semiconductor switch 26, 27 or 28, to the negative side $-U_B$ of the voltage source. For the commutation operation each of the semiconductor switches 26, 27, 28 is controlled by a respective magnetic-field-sensitive position sensor 30, 31, 32. The position sensors can in particular be Hall generators or Hall IC's which are, in turn, controlled by the rotor magnetic arrangement 11.

As a result of the given geometry, the position sensor 30 can be arranged on the stator at eight different locations along the air gap 16, of which four locations are denoted by 30a, 30b, 30c and 30d in Fig. 1. The other four possible locations are located diametrically opposite to respective ones of the depicted locations. It has been found that one can in a simple way avoid the position sensors being influenced by the field from the stator coils, and avoid the resulting undesired shifting of the commutation time points, by so arranging the position sensors 30, 31, 32 at the air gap 16 that, in each instance, the one of the position sensors which effects the commutation of the winding's current from one to another of the winding's conductors is located at a place where a current-carrying coil is present neither before nor after the commutation operation. The position sensor 30 effects the commutation from the stator coil 22 to the stator coil 23 by rendering the semiconductor switch 26 non-conductive and by rendering the semiconductor switch 27 conductive. The criterion stated above is fulfilled for position sensor 30 if the latter is arranged at the positions 30a or 30c; in contrast, it is not fulfilled at the positions 30b and 30d. The position 30a is located on the radial symmetry axis of the main pole 17 carrying the coil 24,

i.e., the one of the coils which is not involved in the commutation operation triggered by position sensor 30. The second advantageous position 30c for the position sensor 30 is located beneath that one of the auxiliary poles 19 found between the neighbouring stator coils 22, 23, as between which latter the winding's current is commutated under the influence of the position sensor 30. In contrast, the positions 30b and 30d for the position sensor 30 are excluded in accordance with the aforesaid criterion. At position 30b the position sensor 30 would be subjected to the magnetic field of coil 23 after the commutation operation, whereas at position 30d the position sensor would be subjected to the coil 22 prior to the commutation operation.

Corresponding remarks apply to the other two position sensors 31, 32; the positions in principle possible for these within the illustrated region of 180°-mech. are denoted by 31a, 31b, 31c, 31d and 32a, 32b, 32c, 32d, respectively. Here again, of these positions only the positions 31a, 31c and 32a, 32c fulfill the presently set forth criterion.

The foregoing explanation of Fig. 1 presupposes three-pulse operation, i.e. the rendering conductive at any given time of only one of the winding's three conductors, the flow of current through each of the winding's conductors always being in the same direction. The stator coils 22, 23, 24 and the semiconductor switches 26, 27, 28 accordingly form a circuit configuration which can be designated as half of a bridge circuit. However, the invention is not limited thereto. The described motor can rather operate with a full bridge circuit permitting a reversal of the direction of the winding's currents (such a full bridge circuit is for example known from Fig. 6b of DE-OS 30 44 027), and the motor can be operated in six-pulse fashion, in which case at any given time two of the winding's conductors carry current simultaneously. Referring to Fig. 1 it may be noted that, in the case of six-pulse operation, only the positions 30c, 31c, 32c fulfill the criterion that the position sensor effecting the commutation from one to another of the winding's conductors be located in that region of the stator in which a current-carrying coil is located neither prior to nor subsequent to the commutation operation.

The use of at least eight permanent-magnetic poles has furthermore the advantage that the forces exerted on the rotor shaft are symmetrical with respect to the motor axis.

The Hall element positions as discussed above have particular significance when the motor of Fig. 1 is operated in the manner shown in Fig. 4, although persons skilled in the art will understand that other and equivalent contexts may also be employed. Fig. 4A shows the output voltage of one of the motor's three Hall elements. This voltage is cyclical and has a period equal to 360°-electrical.

The Fig. 4A voltage is applied to a comparator, or other conventional pulse shaper, to yield the better defined voltage waveform of Fig. 4B, each pulse of which lasts for 180°-electrical. The same applies for the other two Hall elements, but preferably their respective pulse trains are phase-shifted one from the other by 120°-electrical, as shown for the three Hall elements in Fig. 4c, i.e., due to the locations of these three elements. The set of three pulse trains of Fig. 4C is applied to a logic circuit to generate three different pulse trains shown in Fig. 4D. The pulses in each of these trains have a duration of 120°-el., a period of 360°-el., and the three pulse trains are phase-shifted one from the next by 120°-el. Each of the three pulse trains is used to render conductive a respective one of the three transistors 26, 27, 28, so that Fig. 4D also represents the respective conduction times of these transistors. Figs. 4E1, 4E2, 4E3 depict the potential and (in the shaded areas) the actual torque contributors of respective ones of the three coil systems. If the respective transistor of one of these coil systems were always conductive, the associated torque contribution would be sometimes in the correct rotation direction (positive) and sometimes in the non-desired rotation direction (negative); therefore, in this example, the transistors 26–28 are never rendered conductive at times that would produce wrong-direction torque. As can be seen, if one considers only positive half-cycles of torque (each having a duration of 180°-el.), the torque has a relatively uniform level only during about 120°-el. of the 180°-el. half-cycle; for the approximately 30°-el. at the start and end of each half cycle, the potential torque contribution is far from being of a steady value. Thus, as shown by the shaded areas, only the 120°-el. intervals are acutally employed; i.e., as shown by the transistor conduction times in Fig. 4D, the respective ones of the three coil systems are energized by current only at the times when their torque contributions will be of steady value.

It is emphasized that the manner of operation shown in Fig. 4 is but examplary, it being the case that the motor employs three constituent torque pulses per 360°-el. Persons skilled in the art will understand that the motor could furnish six such pulses if, for each coil system, during the 120°-el. time interval which is shifted by 180°-el. from the respective shaded area, the coil system were to be energized by current of reversed direction, e.g. supplied to the three coil systems by three further transistors or by other such means.

The substantial closing up of the stator's surface facing the air gap 16 by means of the auxiliary poles 19 is desired to a high degree, because a large part of the rotor magnetic field crossing over in the illustrated construc-

tion to the auxiliary poles would, upon omission of the auxiliary poles, be pulled to the main poles 17 and added thereto. Functionally this would have the same effect as if the pole faces 18 of the main poles 17 were substantially wider than 180°-el., which would be equivalent to chording. Furthermore strong jolting would occur. Both these things are avoided by means of the auxiliary poles 19. On the other hand, however, the auxiliary poles 19 hinder the installation of the non-overlapping coils 22, 23, 24 into the respective stator slots 34.

In order on the one hand to keep small the slot openings between the main pole faces 18, but on the other hand to provide for windability in a manner suited to assembly needs, the auxiliary poles in the three-phase collectorless D.C. motor of Fig. 2 (where for simplicity the rotor is not shown) are not stamped out together with the main poles from the sheet metal of the stator's sheet metal stack but instead are designed as separate pole bodies 36 which can be afterwards inserted into corresponding recesses 37 in the stator's sheet metal stack. In this embodiment the main poles 17 are wound with the stator coils 22, 22', 23, 23' and 24, 24', during which the pole bodies 36 forming the auxiliary poles 19 are not yet inserted. Only after the winding of the main poles are the pole bodies 36 pushed into the recesses 37 in order to substantially close up the slot openings 39. The pole bodies 36 preferably consist of non-laminated, solid material. The circumferential extent of 60°-el. of the auxiliary poles is relatively small compared to the circumferential extent of 180°-el. of the main pole faces 18 and, in correspondence thereto, they accept only a relatively small magnitude flux; as a result, pole bodies 36made from solid material do not lead to substantial eddy-current losses. The pole bodies 36 can advantageously be fabricated from sintered material, especially sintered iron. The sintering process permits the manufacture of dimensionally accurate shapes without subsequent machining. Furthermore suitable for the pole bodies 36 are siliconized iron types, such as for example commercially available from the Vakummschmelze Company under the trade name "Trafoperm".

The pole bodies 36 provided to form the unwound auxiliary poles 19 can advantageously be provided with recesses 40 (Fig. 3) to accomodate the position sensors 30, 31, 32. Especially when the pole bodies 36 are fabricated using a sintering technique, this necessitates practically no further fabrication cost.

It is understood that, with the arrangement of Fig. 2, the rotor can be designed in the same way as in the case of Fig. 1. Whereas Figs. 1 and 2 depict internal-rotor motors, it is furthermore to be understood that the expedients described above can with advantage be applied in the same way in the case of external-rotor motors.

CLAIMS

1. A three-phase collectorless D.C. motor with a permanent-magnet rotor magnet arrangement having at least two pole pairs and a star-connected three-conductor stator winding, the winding's conductors being arranged non-overlapping in slots of a slotted stator, with their currents being controlled via at least three semiconductor elements by at least three magnetic-field-sensitive position sensors, the latter in turn being controlled by the rotor magnet arrangement, wherein the position sensors are distributed along the stator's circumferential direction in such a manner relative to the stator winding's conductors that, at each commutation operation, that one position sensor which effects the commutation of the winding's current from one to another of the winding's condutors is provided in a region of the stator in which a current-carrying coil is present neither immediately before nor immediately after the commutation operation.

2. A D.C. motor according to claim 1, wherein the number of stator poles stands in the ratio 3:4 to the number of rotor poles and each of the stator poles has a breadth of substantially 180°-el.

3. A D.C. motor according to claim 1 or claim 2, wherein, considered in the circumferential direction, each position sensor is located substantially midway between those neighboring coils between which the commutation of the winding's current occurs under the influence of the position sensor in question.

4. A D.C. motor according to any preceding claim wherein, the position sensors are each located substantially on the radial-symmetry axis of that one of the stator poles which is carrying that one of the coils not involved in the commutation operation triggered by the respective position sensor.

5. A D.C. motor according to any one of the preceding claims, wherein the motor is designed as a three-pulse motor.

6. A D.C. motor as claimed in claim 3, wherein the motor is designed as a six-pulse motor with at least four magnetic pole pairs.

7. A D.C. motor according to any one of claims 1 to 6, wherein at the air gap the space remaining in the circumferential direction between each two neighboring stator poles is substantially filled up by an unwound auxiliary stator pole.

8. A collectorless D.C. motor with a permanent-magnet rotor magnet arrangement and a slotted stator which carries a stator winding wound in non-overlapping manner, the stator having a succession of poles which are integrally connected to one another, wherein intermediate each pole and the next there is an auxiliary pole connectable to the

stator after winding.

9. A D.C. motor according to claim 8, wherein the auxiliary poles are the unwound poles.

10. A D.C. motor according to claim 8 or claim 9, wherein the auxiliary poles are inserted into recesses of the stator.

11. A D.C. motor according to any one of claims 8 to 10, wherein each auxiliary pole is in the form of a one-piece pole body.

12. A D.C. motor according to claim 11, wherein the auxiliary poles are fabricated from solid material.

13. A D.C. motor according to claim 12, wherein the auxiliary poles are sintered bodies.

14. A D.C. motor according to any one of claims 8 to 13, wherein the auxiliary poles are provided with recesses for accomodating position sensors.

15. A D.C. motor as claimed in any one of claims 8 to 14 which is also as claimed in any one of claims 1 to 13.

16. A D.C. motor, substantially as hereinbefore described with reference to and as illustrated in Fig. 1 or Figs. 2 and 3 of the accompanying drawings.

17. A collectorless D.C. motor with a permanent-magnet rotor magnet arrangement and a stator winding having a plurality of conductors, with their currents being controlled by magnetic-field-sensitive position sensors, the latter in turn being controlled by the rotor magnet arrangement, wherein the position sensors are distributed along the stator's circumferential direction in such a manner relative to the stator winding's conductors that, at each commutation operation, that position sensor which effects the commutation of the winding's current from one to another of the winding's conductors is provided in a region of the stator in which a current-carrying coil is present neither immediately before nor immediately after the commutation operation.

Printed in the United Kingdom for
Her Majesty's Stationery Office, Dd 8818935, 1985, 4235.
Published at The Patent Office, 25 Southampton Buildings,
London, WC2A 1AY, from which copies may be obtained.